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ABSTRACT

Most transuranic (TRU) wastes are destined for the Waste Isolation Pilot Plant (WIPP). However, the TRU wastes from the cleanup of U.S. nuclear weapons accidents are classified for national security reasons and cannot be disposed in WIPP. The U.S. Department of Energy (DOE) sought an alternative disposal method for these "special case" TRU wastes and from 1984 to 1987, four Greater Confinement Disposal (GCD) boreholes were used to place these special case TRU wastes a minimum of 21 m (70 ft) below the land surface and a minimum of 200 m (650 ft) above the water table. The GCD boreholes are located in arid alluvium at the DOE's Nevada Test Site (NTS). Because of state regulatory concerns, the GCD boreholes have not been used for waste disposal since 1989.

DOE requires that TRU waste disposal facilities meet the U.S. Environmental Protection Agency's (EPA's) requirements for disposal of TRU wastes, which are contained in 40 CFR 191.
This EPA standard sets a number of requirements, including probabilistic limits on the cumulative releases of radionuclides to the accessible environment for 10,000 years. The DOE Nevada Operations Office (DOE/NV) has contracted with Sandia National Laboratories (Sandia) to conduct a performance assessment (PA) to determine if the TRU waste emplaced in the GCD boreholes complies with the EPA's requirements.

Sandia has completed the PA using all available information and an iterative PA methodology. This paper overviews the PA of the TRU wastes in the GCD boreholes [1]. As such, there are few cited references in this paper and the reader is referred to [1] and [2] for references. The results of the PA are that disposal of TRU wastes in the GCD boreholes easily complies with the EPA's 40 CFR 191 safety standards for disposal of TRU wastes. The PA is undergoing a DOE Headquarters (DOE/HQ) peer review, and the final PA will be released in FY2001 or FY2002.

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1 Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United State Department of Energy under Contract DE-AC04-94AL85000.

INTRODUCTION

In implementing its atomic energy defense mission, the DOE generates and is responsible for the safe disposal of several different types of radioactive waste. In general, each type of waste is disposed using different techniques and/or facilities. For example, LLW is generally disposed of using shallow land burial techniques and the WIPP near Carlsbad, New Mexico has been approved by the EPA for disposal of certain TRU wastes.

There are some "special case" wastes that do not meet the waste acceptance criteria for the default disposal techniques and/or facilities. Development of GCD boreholes grew out of the need to safely dispose of several types of special case wastes.

DISPOSAL HISTORY

In 1981, DOE began activities to demonstrate the feasibility of using GCD boreholes for disposal of high-specific activity LLW. This disposal method consists of boreholes approximately 3 m (10 ft) in diameter and 37 m (120 ft) deep. The bottom 15 m (50 ft) is used for waste disposal and the upper 21 m (70 ft) is backfilled with native alluvium. The GCD concept was so named because it provides greater confinement than shallow land burial.

The first borehole, the GCD Test (GCDT) borehole, was constructed in 1983. GCDT was augured, instrumented, loaded with wastes, and monitored in order to test the GCD disposal concept. Figure 1 shows the placement of monitoring equipment in the GCDT borehole. The tests consisted of burying 500,000 curies of heat-producing cobalt, cesium, and strontium sealed sources with 700,000 curies of tritium and measuring the releases of tritium, and other factors [3].

These tests were judged to be successful [4] and twelve more boreholes were augured and used to dispose of additional radioactive wastes including TRU waste. Boreholes 1, 2, and 3 contain special case TRU wastes from nuclear weapons accidents and borehole 4 contains waste materials from nuclear weapons production or disassembly. In total, about 60,000 kg (132,000 lbs) of TRU waste packages, containing less than 6 kg (13 pounds) of plutonium 239 were buried in the four boreholes. The average specific activity of transuranic elements is greater than 5,000 nano-curies per gram of waste. All of the TRU wastes emplaced in the GCD boreholes are for IPP. Because of state regulatory concerns, the GCD boreholes have not been used for waste disposal since 1989.

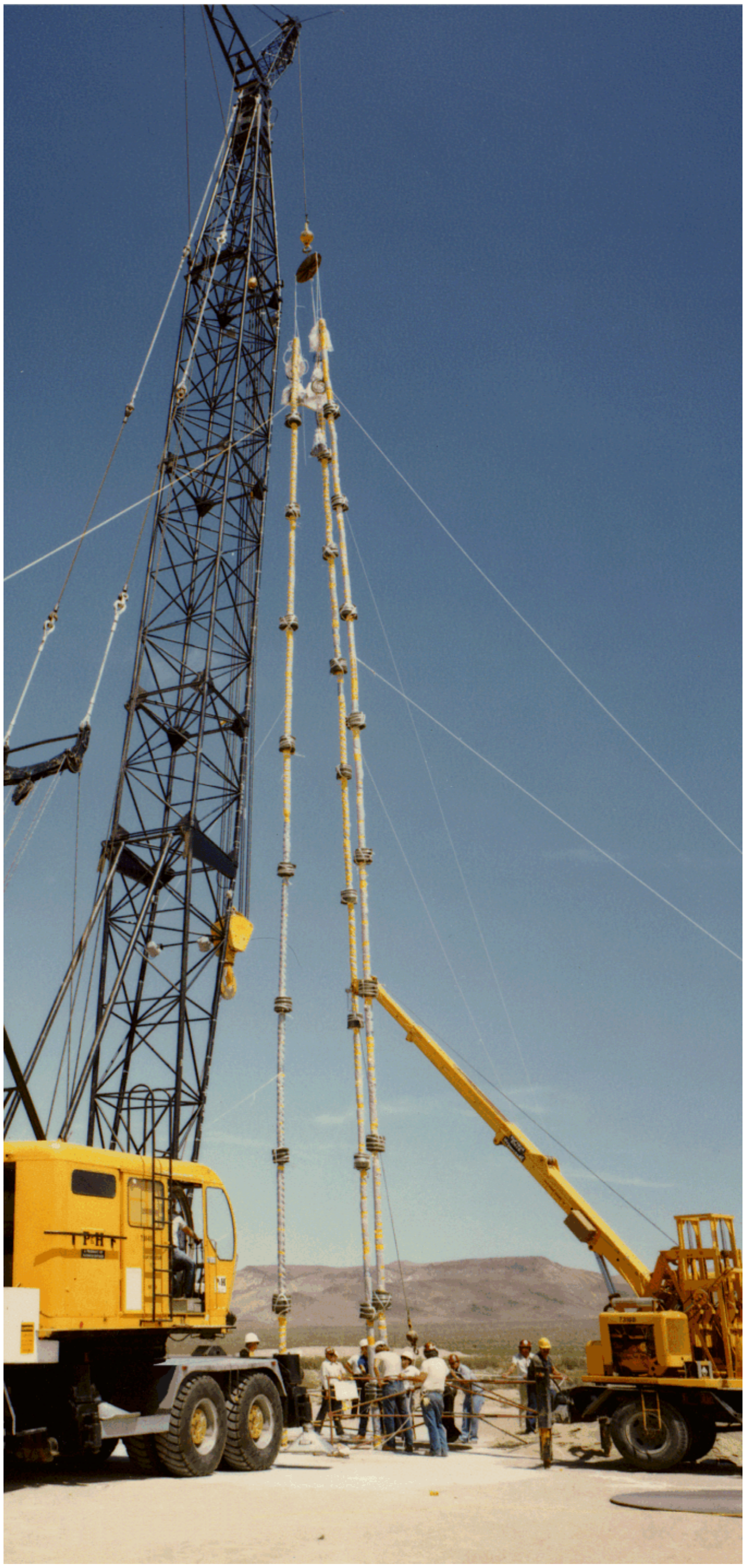

Figure 1 Placement of Monitoring Equipment in the GCDT Borehole.

SITE SETTING

The GCD boreholes are located in the Area 5 Radioactive Waste Management Site (RWMS), which in turn is located on the Nevada Test Site (NTS), which occupies 3,500 km^2 (1,350 mi^2) of government-owned land. The NTS, in turn, is located in southeastern Nevada, approximately 105 km (65 mi) northwest of Las Vegas, and is in the southern part of the Basin and Range geologic province. The basin and range province is characterized by north-south trending mountains separated by alluvial filled basins.

The Area 5 RWMS is located in the Frenchman Flat basin of the NTS, and is situated on a thick sequence of arid alluvium, composed of weakly stratified, gravelly sand. Frenchman Flat basin has been filling with alluvium for more than 8,000,000 years. The exact rate of basin filling is not known, but the average rate of filling is about 3 cm (1.3 in.) per 1000 years. Based on measurements from a number of characterization wells, groundwater is approximately 236 m (774 ft) below the land surface. The average precipitation is 13 cm/yr (5 in./yr). The limited precipitation, coupled with generally warm temperatures, plant uptake, and low humidities, results in a hydrologic system dominated by evapotranspiration.

The movement of water within this 236 m (774 ft) thick unsaturated zone can be subdivided into two zones; the near surface zone and the deeper zone. In the near surface, precipitation is pulled downward by gravity and is either aided or resisted by the capillary tension of the soil. The forces acting to remove the moisture include evaporation and plant root uptake. The *average* volumetric moisture content in the near surface zone is very low, ranging from 1% to 3%. Based on a number of field studies, the balance of these forces is such that (approximately) the upper 2 m (7 ft) is hydrologically active, and aerially-distributed infiltration never infiltrates deeper than about 2 m (7 ft) in the interfluvial regions. The Area 5 RWMS is in an interfluvial region.

Under current climatic conditions, water-soluble constituents, such as chloride, are carried downward by infiltrating moisture, only to be deposited at about 2 m (7 ft) depth, as the infiltrating moisture is removed by evaporation and plant uptake. This process (a) moves water soluble constituents to the lower boundary of the near surface zone, and (b) provides a marker of the depth of infiltration. The bottom of this zone can be thought of as a *"no-flux" boundary for the water soluble constituents,* based on the net effect of this transient cycling.

A number of plants have adapted to the arid climate of the desert southwest. Plant roots absorb minerals and heavy metals, carrying those minerals and metals to the plant's above-ground biomass. A plant uptake model which reflects rooting depths, biomass turnover, and the ability of plants to uptake radionuclides is described in the PA. Probability distribution functions (PDFs) are used to accurately describe uncertainties in the root depth distributions, uptake factors for different radionuclides, and biomass turnover rates.

Mammals and invertebrates burrow into the desert soils and this burrowing has the potential to transport contaminated soil from the subsurface to the surface. A model describing the effects of such bioturbation is presented in the PA. The input parameters for the burrowing models are also described using PDFs to capture uncertainties in the effective values. The plant uptake model and the bioturbation model are well developed, because *these are the two processes that can move radionuclides across the no-flux boundary to the accessible environment*.

The deeper vadose zone is hydrologically inactive. The volumetric water content in the deeper zone is approximately 8%. This low-volumetric water content impedes the flow of liquid by significantly reducing the hydraulic conductivity. Between a depth of 2 and approximately 35 m (7 and approximately 115 ft), the alluvium shows decreasingly negative matric potential with depth (for example, (-) 10 bars at 35 m (115 ft) depth and (-) 75 bars at 5 m (15 ft) depth), indicating an *upward gradient in the pore water* (i.e., if the pore water moves, it moves upward and there is no groundwater recharge).

The upward movement of pore water from 35 m (115 ft) deep has been studied extensively and is the result of a system in transition, where the transition times are on the order of thousands of years. From 50,000 to 20,000 years ago, the climate was wetter and cooler (a pluvial). During this wetter and cooler time period, there was deep infiltration, but no aerially-distributed recharge to the water table. Only under surface-water drainage features (fluvial channels) was there recharge to the water table 50,000 to 20,000 years ago. A more xeric environment now exists, and the drying of the land surface is pulling moisture from depth, resulting in the *very slow upward flux of pore water* evidenced by the soil matric potentials. A good analogy is the drying of a moist sponge, where the evaporation of water from the surface of the sponge is slowly pulling water from deeper in the sponge.

The rates of moisture movement in the upper 35 m (115 ft) of the deep vadose zone are far too slow to be measured. Four studies, based on three techniques, were used to estimate the rate of upward specific discharge. Based on these studies, there is a 90% likelihood that the range of upward specific discharge will be from 0.01 to 0.4 mm/yr. From approximately 35 to 90 m (115 to 300 ft) below the surface, there is a static zone where the hydraulic gradient is negligible and from approximately 90 to 236 m (300 to 775 ft), very slow gravity drainage is still occurring.

Over the next 10,000 years, the Area 5 RWMS will change. The changes will occur because:
- operation and closure of the Area 5 RWMS has “disturbed” the site conditions;
- future human activities could inadvertently alter site conditions; and
- natural processes that operate on long time scales may alter site conditions.

There is uncertainty in how much these driving forces will change the Area 5 RWMS over the next 10,000 years. Nonetheless, 40 CFR 191 requires the PA to identify, examine, and estimate cumulative releases caused by “all significant processes and events” that could affect the disposal system for 10,000 years.
As a result of applying the scenario screening methodology, four significant processes and events were identified: climate change, landfill subsidence, exploratory drilling accidently penetrates GCD TRU wastes, and irrigated agriculture accidently occurs on top of the Area 5 RWMS. Of these four, exploratory drilling and irrigated agriculture were assessed and screened out. Based on the EPA’s 40 CFR 191 Appendix B Guidance, exploratory drilling was screened out because there is no (regulatory) consequence, and irrigated agriculture was screened out

because it is not viable at the Area 5 RWMS. The two remaining events, climate change and landfill subsidence, are discussed below.

To assess the potential impact of climate change, this PA examined past global, regional, and site-specific empirical records of proxies of past climatic conditions. All of the empirical records showed a cyclic pattern of climate change in which the climate varies between relatively persistent glacial climates (cooler, wetter, pluvial periods) separated by interglacial climates (warmer, drier periods) of relatively short duration. At the Area 5 RWMS, cooler and wetter equates to 3^{o} to 5^{o} C cooler, with a doubling of average annual precipitation, from 13 to 26 cm/yr (5 to 10 in./yr). During pluvial periods, there was deeper infiltration of surface moisture and open piñon-juniper woodlands existed at the elevations of the Area 5 RWMS.

The accumulation of anthropogenically-derived carbon dioxide (a greenhouse gas) may alter near-term climatic conditions. The effects of anthropogenic climate change were assessed for the nearby Yucca Mountain facility using an expert elicitation based on available data and models and it was concluded that anthropogenic climate change will have a negligible impact at the NTS.

Wastes in the GCD boreholes and the RWMS pits and trenches contain a significant amount of void space, resulting from incomplete filling of waste containers, limited internal compaction of contents, and voids between containers. These voids will produce significant subsidence as the waste containers deteriorate and collapse.

A screening analysis was conducted to determine if the combined effects of landfill subsidence, precipitation, and a return to glacial climatic conditions might cause surface water to migrate to the water table during the next 10,000 years. Four coupled analyses were undertaken for the study: (1) modeling the geometry of future subsidence features; (2) using current climatic data to model precipitation, local runoff, and flooding; (3) using data for glacial climatic conditions to model precipitation, local runoff, and flooding; and (4) using the VS2DT code to model the two-dimensional movement of water in the subsurface.

The screening analysis overestimated the potential for surface water to migrate to the aquifer by making a number of conservative assumptions, such as the assumption that all rare precipitation events were assumed to begin after the loss of institutional control. Under the current climate, 90 100-year storms, nine 1000-year storms, one 10,000-year storm, and one probable maximum precipitation storm were all assumed to occur at short intervals, beginning in year 2170. This screening analysis is presented in the PA.
The key result of the screening analysis was that there could be deep infiltration of surface moisture because of the capture and focusing of precipitation (current and glacial climates), but the moisture will not reach the water table in 10,000 years.

Based on the PA methodology, the combined effects of subsidence, climate change, and flooding that result in downward movement of water are screened out of the PA, maintaining the more conservative upward pathway. To account for the concern that subsidence and/or subsidence plus climate change will cause the return of deeper-rooted piñon-juniper woodlands, all realizations of the PA model were made with the current upward movement of pore water, coupled with the downward, deeper-rooted piñon juniper woodland glacial plant community.

Because the GCD boreholes contain significant quantities of fissile materials (plutonium and highly enriched uranium), an analysis of the potential for a nuclear criticality to occur in the GCD boreholes is presented in the PA.

Solubilities of the TRU-waste radionuclides in Area 5 RWMS pore water are developed in the PA, with PDFs used to describe uncertainties. Other factors influencing the movement of radionuclides include diffusion, dispersion, retardation, and radon gas transport. Each of these, and the general transport model, are discussed in the PA.

PERFORMANCE OBJECTIVES

At the time of emplacement, DOE-titled TRU waste was governed by Chapter II of former DOE Order 5820.2 which required that TRU waste disposal systems must meet the EPA's requirements for disposal of TRU wastes which (in this case) is *the 1985 version* of 40 CFR 191. 40 CFR 191 includes four sets of requirements: Containment; Assurance; Groundwater Protection; and Individual Protection.

<u>Containment Requirements</u> The disposal system shall provide the **reasonable expectation**, based on a PA, that the cumulative releases of radionuclides **to the accessible environment** for 10,000 years after disposal from all significant processes and events shall:

(a) have a likelihood of less than one chance in 10 of having an EPA Sum greater than one, and
(b) have a likelihood of less than one in 1,000 of exceeding an EPA Sum of 10.

The EPA sum is the ratio of the calculated, commutative releases (the calculated, total curies that migrate to the accessible environment in 10,000 years) divided by the number of curies set by the release limit. The release limit is calculated using the inventory and a table in the back of 40 CFR 191.

<u>Assurance Requirements</u> The Assurance Requirements state that the DOE must: maintain active institutional controls; monitor the disposal system; and undertake other actions related to closure. Demonstrating compliance with the Assurance Requirements is not addressed in this paper.

<u>Individual Protection Requirement</u>s The disposal system shall provide a reasonable expectation that, for 1,000 years after disposal, **undisturbed performance** of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public **in the accessible environment** to exceed 25 millirems to the whole body or 75 millirems to any critical organ. The EPA defines **undisturbed performance** as: "the predicted behavior of a disposal system, including consideration of the uncertainties in the predicted behavior, **if the disposal system is not disrupted by human intrusion** or the occurrence of unlikely natural events." Therefore, there is no dose standard for inadvertent human intrusion.

Groundwater Protection Requirements   Disposal systems shall be designed to provide a reasonable expectation that, for 1,000 years after disposal**, undisturbed performance** of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of **a special source of ground water** to exceed standards defined in the regulation. 40 CFR 191 defines a **special source of ground water** as those Class 1 ground waters ... that: (1) are within the Controlled Area boundary; (2) are supplying drinking water for thousands of persons, as of the date that the site was chosen for waste disposal; and (3) are irreplaceable. Because there is no special source of ground water within 5 km (3.1 mi) of the GCD boreholes, the GWPRs of 40 CFR 191 do not apply to the GCD boreholes.

In 1987, the U.S. Court of Appeals remanded the 1985 version of 40 CFR 191. After additional deliberation, the EPA published the current version of 40 CFR 191 in 1993. There were a number of significant changes to the Individual Protection Requirements and the Groundwater Protection Requirements. The reader is referenced to [5] for details. Between the 1985 and 1993 versions of 40 CFR 191, there is no change to the Containment Requirements, which are the "primary" requirements in 40 CFR 191. The EPA informed the DOE that the 1985 version of part 191 was applicable to any disposal activities at the GCD boreholes. [p. 66413 of [5]]

TREATMENT OF UNCERTAINTY

In 40 CFR 191, the EPA requires the use of PA to demonstrate that the *future performance* of a disposal system will be protective of human health for the next 10,000 years. This section overviews the PA methodology, which provides confidence in the PA analysis and results.

Performance Assessment Methodology Overview Fundamental to this methodology is the philosophy that this PA is not a prediction of how the GCD system will actually perform. Actual performance cannot be predicted (as the future is unknowable). Rather, this PA provides simulations of a range of plausible outcomes, *which are developed in a manner to provide confidence that the results of the analysis do not overestimate the ability of the GCD boreholes to protect human health as required by 40 CFR 191.*

This methodology includes the following principles: (1) all events and processes that can adversely affect the system performance are analyzed; (2) if more than one possible interpretation or conceptual model of the system can be justified, each
tion is considered and resources are focused on evaluating those interpretation(s) that may lead to non-compliant results (i.e., the conceptual model used in the PA is biased); (3) parameter uncertainty and/or variability is addressed by sampling from the unbiased distribution of possible parameter values; (4) Monte Carlo simulations are used to propagate parameter uncertainty through the analysis; and (5) these principles are implemented in an iterative PA framework.

Conceptual Model Uncertainty and Screening   A conceptual model is effectively a set of assumptions that describe the system for a specific purpose. Because the spatial and temporal characteristics of a disposal system are imperfectly known and cannot be predicted for the next

10,000 years, there may be multiple conceptual models that are consistent with existing site data. Ideally, all possible conceptual models would be carried through the entire PA; however, for practical reasons, the number of conceptual models addressed in this PA has been reduced through the use of a conceptual model screening process, which includes the following:

- identify alternative conceptual models that are consistent with existing knowledge;
- analyze all conceptual models to assess ones that might lead to non-compliant results; and
- retain for further consideration and PA analysis those models that could lead to non-compliant results.

The first step may result in multiple descriptions of the disposal system. Often, a combination of technically-defensible arguments and quantitative analysis is used in the second step to screen out conceptual models. If the screening analysis indicates that the use of a particular model would improve disposal system performance (i.e., shifting the CCDF toward lower values or reducing doses), that conceptual model may be (but does not have to be) excluded from further consideration. This screening process is practical, and it maintains the defensibility of PA by biasing the transport models towards higher releases.

<u>Parameter Uncertainty and Variability</u> Parameter uncertainty is defined as a lack of knowledge about a given parameter value. Parameter variability, on the other hand, is heterogeneity in a population. For this PA, probability distributions of *effective values* of parameters have been developed and used to represent the parameter values over the spatial and temporal scales defined in the PA mathematical model. *Unbiased probability distributions* are used to capture uncertainty in the effective values of parameters. Unbiased, as used here, is meant to indicate that the distribution chosen for a given parameter is an accurate representation of the current state of knowledge for that parameter.

<u>Iterative Framework</u> An iterative framework is a very important aspect of this PA methodology. The process advocates beginning the PA with simple, defensible models, in which model uncertainty and parameter uncertainty are managed as described above. If compliance is demonstrated, the PA is complete; if not, sensitivity and data worth analysis are used to guide future activities (e.g., additional site characterization).

<u>Geologic Processes and Future Human Activities</u>

The Area 5 RWMS is located in a very stable geologic setting. For the next 10,000 years, it is expected that these processes will continue. *Consequently, for geologic processes, this PA is based on the continuation of current conditions*. Note that current conditions include processes operating over tens of years (e.g., changing plant species) and processes operating over thousands of years (e.g., climate change).

Human history is much, much shorter than the geologic record. Human societies, with written languages and technological advances, have only existed for a few thousand years. Given this short record, projecting human activities for the next 10,000 years is more difficult. *For future human activities, this PA relies on the EPA's Appendix B Guidance on how to assess future human interactions with the GCD system.* This approach for addressing geologic processes and future human activities is similar to the approach advocated by the National Academy of Sciences. [6]

PERFORMANCE ASSESSMENT MODEL

Models of radionuclide release and transport were developed and used to assess compliance with the requirements of 40 CFR 191. These models are based on the geology, biology, climate, and undisturbed hydrology of the Area 5 RWMS, and include upward liquid-phase advection of radionuclides, along with diffusion and dispersion; diffusion of vapor-phase radionuclides; plant uptake; bioturbation; adsorption; precipitation; and radioactive decay and production. Modeling assumptions are discussed throughout the PA and are summarized in the summary tables in the PA.

The Individual Protection Requirements require estimation of doses to a member of the public during the first 1,000 years, assuming undisturbed performance of the disposal system. This involves (a) supplementing the transport model already implemented for the Containment Requirements, and (b) developing an exposure/dose model. This PA uses a very simple (and very conservative) transport model and two exposure scenarios; a gardening scenario and a home construction and occupancy scenario. In the first scenario, all radionuclides released to the accessible environment for the first 1,000 years are "accumulated" and placed in a garden for the dose assessment model for the resident farmer. In the second exposure scenario, all radionuclides released to the accessible environment for the first 1,000 years are accumulated and placed over a GCD borehole. The member of the public receives a dose from home construction and occupancy, including doses from radon. These models are discussed in detail in the PA.

The simplicity of these PA models allowed them to be implemented in Microsoft® Visual Basic™ macros in an Access™ database. The first set of macros calculates the movement and cumulative releases of 19 different radionuclides over a 10,000-year regulatory period, producing a Complementary Cumulative Distribution Function (CCDF) that is used to assess compliance with the Containment Requirements of 40 CFR 191. The second set of macros calculates the movement and cumulative releases of 19 different radionuclides over a 1,000-year regulatory period and then approximates the dose to a member of the public resulting from exposure to these 19 radionuclides and their progeny, producing an estimate of dose that is used to assess compliance with the Individual Protection Requirements. The same release and transport model is used in both sets of macros.

PA RESULTS

<u>Containment Requirements</u> The probability distribution for integrated normalized release was estimated using 5,000 samples of the uncertain parameters for the Containment Requirements model. For each parameter sample set, integrated release was calculated over the 10,000-year performance period of the Containment Requirements. Figure 2 shows the resulting CCDF of integrated normalized release. The critical points of regulatory compliance for comparison

against the Containment Requirements are also shown on the figure. The Containment Requirements require that the integrated release at a probability level of 0.1 be less than 1, and that the integrated release at a probability level of 0.001 be less than 10. The region representing violation of the Containment Requirements is shaded. The estimated CCDF easily satisfies both quantitative limits defined in 40 CFR 191.

<u>Individual Protection Requirements</u> Probability distributions for dose were calculated using two exposure conditions: an off-site resident farmer, and an on-site homebuilder. In both conditions, dose was estimated using 1000 samples of the uncertain transport and exposure parameters. For each parameter sample set, dose was calculated at the end of the 1000-year performance period. In the off-site farmer condition, all radionuclides crossing the land surface boundary during the 1000-year period were assumed to have collected in the garden soil. Figure 3 shows the histogram of doses to those organs receiving relatively large doses. The average whole-body dose was 4.7 _ $10^{å3}$ mrem and the average dose to bones, which typically received the largest dose of any organ, was 0.12 mrem. All calculated dose values are far below the limits of 25 mrem for whole-body dose and 75 mrem for critical organ dose imposed by the IPR.

CONCLUSIONS

The PA described in this document was performed to assess compliance with the quantitative requirements of 40 CFR 191. As such, the analyses have been tailored to these EPA standards, and provide a quantitative basis for deciding whether or not disposal of TRU waste in GCD boreholes is protective of human health and the environment.

The models used to analyze the release and transport of radionuclides are based on knowledge of the disposal system geology, biology, climate, geochemistry, and hydrology. Radionuclide releases and potential doses are estimated based on models of the system as it now exists and as it might exist in the future. The results of the PA indicate that disposal of TRU waste in GCD boreholes is protective of human health and the environment in that it meets the quantitative requirements of 40 CFR 191. The PA is undergoing a DOE Headquarters (DOE/HQ) peer review, and the final PA will be released in FY2001 or FY2002. Based on the PA methodology, there is a strong, reasonable assurance that actual performance will be better than that which is simulated in this PA.

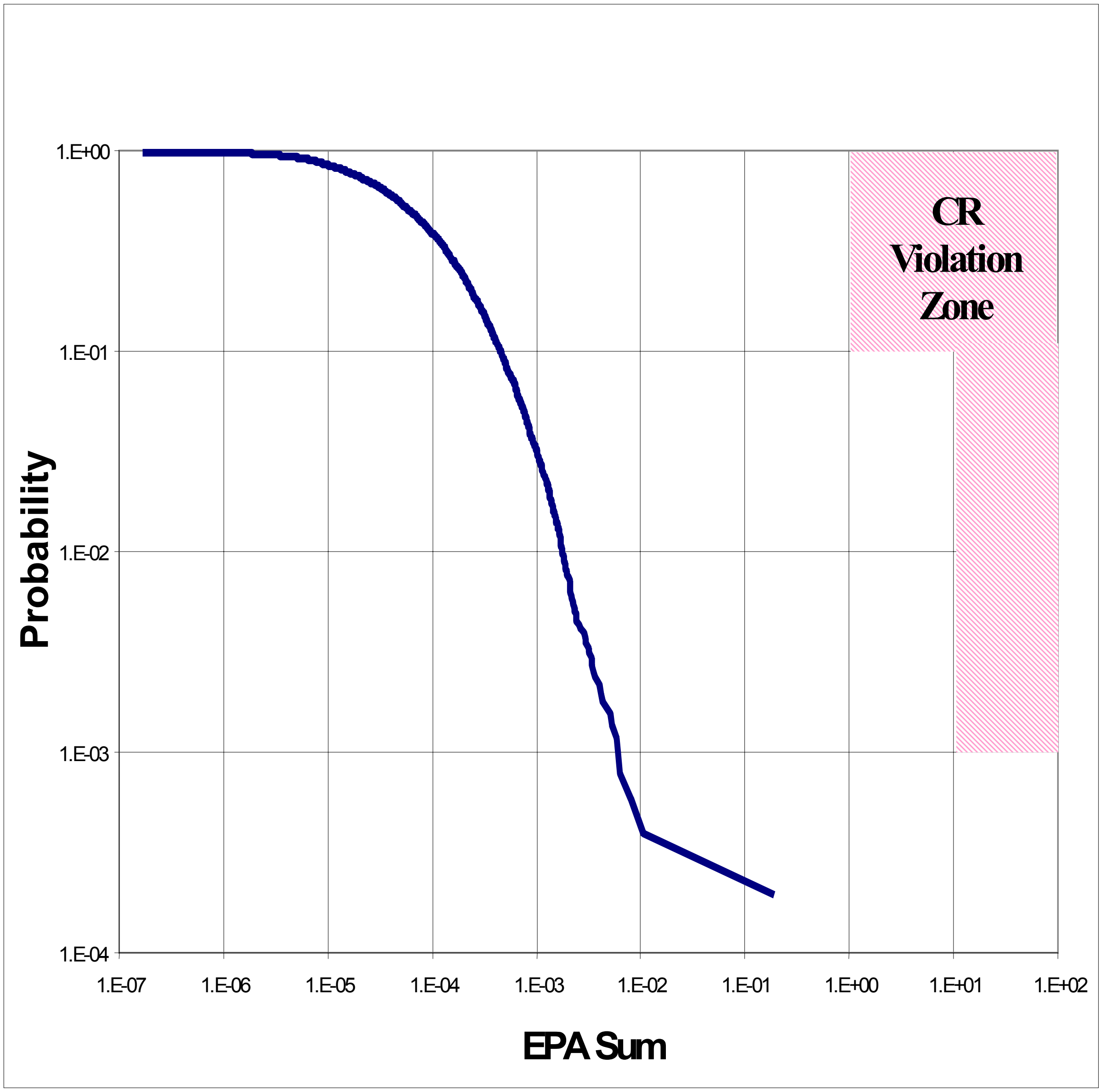

Figure 2 CCDF for the PA Analysis of the TRU Wastes in the GCD Boreholes. Analyses of Alternative Scenarios and Conceptual Models are expected to Result in Reduced Releases, Shifting the CCDF to the Left

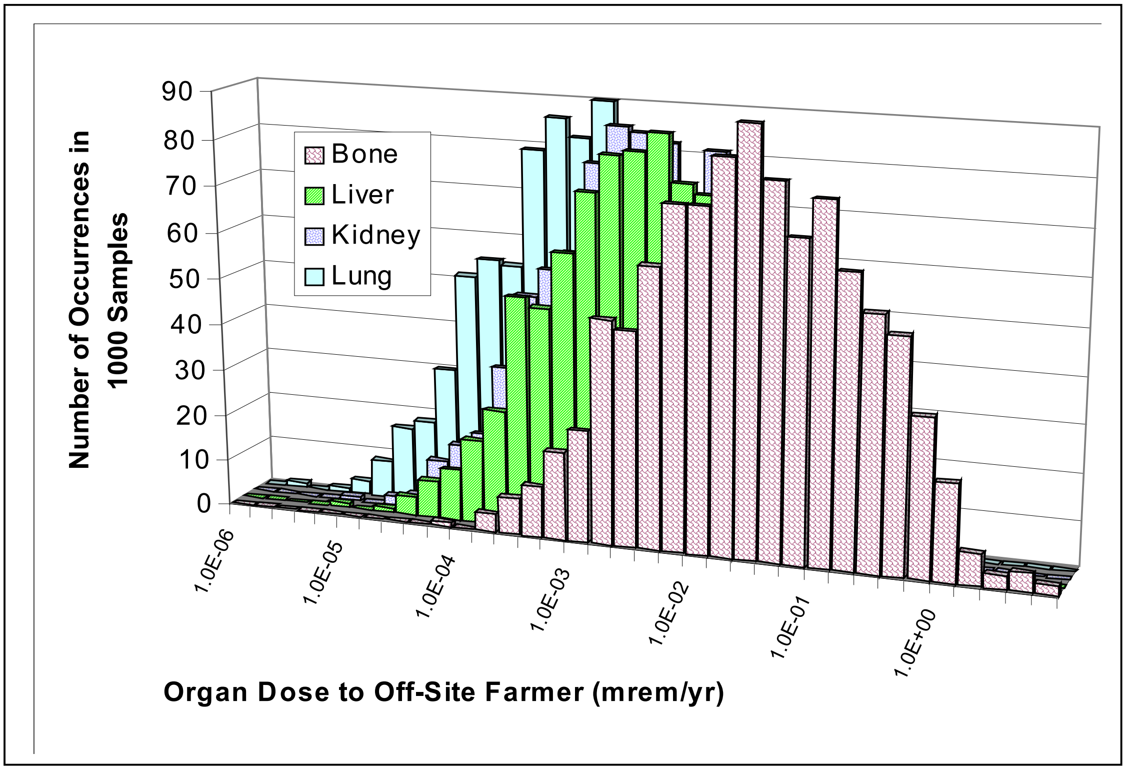

Figure 3. Histogram of Calculated Values of Does to Critical Organs for the GCD TRU Waste IPR Analysis.

REFERENCES

1. Cochran, J.R., Beyeler W.. E., Brosseau D. A., Brush L. H., Brown T. J., Conrad S. H., Crowe,
B.M., Davis P. A., Ehrhorn T., Feeney T., Fogleman W., Gallegos D. P., Haaker R., Kalinina E., Price L.L., Thomas D.P., and Sharon Worth S., 2000, *Compliance Assessment Document for the Transuranic Wastes in the Greater Confinement Disposal Boreholes at the Nevada Test Site, Volume 2: Performance Assessment, Version 1.1.*

2. Cochran, J.R., Crowe, B.M., and Di Sanza, 1999, "Intermediate Depth Burial of Classified Transuranic Wastes in Arid Alluvium," *Proceedings from Waste Management '99*, Session 47, Waste Management Symposia, Inc., Tucson, AZ.

3 . Boland, E.J., and P.T. Dickman. 1986. "High-Specific-Activity Waste Handling for Greater Confinement Disposal," *Abstract for Waste Management '86*. Proceedings of the Symposium on Waste Management at Tucson, AZ. pp. 581.

4. Dickman, P. T., 1989, "Greater Confinement Disposal at the Nevada Test Site, Final Technology Report," prepared by Science Applications International Corp., Las Vegas, NV, for Reynolds Electrical & Engineering Co., Inc., Las Vegas, NV.

5. EPA. 1993. "40 CFR 191: Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule," *Federal Register*, Monday, December 20, 1993.

6. NAS. 1995. *Technical Bases for Yucca Mountain Standards*, National Academy Press, Washington, D.C.